

CARBON BALANCE IN GEORGIA’S INDUSTRIAL SOILS AND ECO-PHYTOREMEDIATION-BASED REGENERATION

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Abstract. Industrial soils are experiencing severe degradation and a sharp decrease in organic carbon content as a result of anthropogenic impacts. This study analyzes the main mechanisms of soil carbon balance disturbance in industrial zones and discusses possible restoration strategies based on ecophytoremediation approaches. The study pays special attention to the possibility of using industrial hemp (*Cannabis sativa*) as one of the most effective means for carbon dioxide sequestration. The methodology is based on the analysis of literary sources, the summary of soil data and the evaluation of practical reclamation models. The results show that the selection of the right plant cover and enrichment with biocarbon contribute to the partial restoration of the carbon balance in industrial soils.

Key words: industrial soils, carbon balance, ecophytoremediation, biocarbon, industrial hemp.

Introduction

Soil carbon storage is a vital ecosystem function driven by the interaction of ecological processes. Soil is a key element in the global carbon cycle. Soil stores a large amount of carbon originating from aboveground and belowground organic matter. However, in industrial areas – where the land surface is subjected to massive human intervention – organic carbon content is sharply reduced. This affects both microbial activity and the physical and chemical structure of the soil. [1,2.] The relevance of the issue is particularly emphasized in the context of climate change, where the soil carbon function is considered a potential means of reducing atmospheric CO₂. The majority of Georgia's economic activities are related to industrial processes, including factories, the distribution of industrial soils, the use of modern technologies, and urban development. These factors affect soil quality, the biosphere, and carbon exchange. [3]

The carbon balance of soils located in industrial zones is significantly disrupted as a result of intensive anthropogenic impact. Such soils are characterized by low organic carbon content, reduced biological activity and structural degradation, which leads to a weakening of the ability to retain carbon. As a result of industrial activities, numerous hectares of soil are contaminated in Georgia, which require restoration and reclassification. The main causes of carbon loss are industrial activities. [4] The process of carbon reduction in uninhabited areas is determined by a number of factors:

- Mechanical disturbance of the land surface as a result of construction, mining or infrastructure works, which leads to the disruption and decomposition of stable organic matter;
- Pollution with heavy metals and chemical compounds, which hinders the functioning of soil microflora and slows down the process of humus formation;
- Soil compaction and disruption of the hydrological balance, which reduces oxygen exchange and slows down microbial destruction, but at the same time contributes to the constant release of carbon;
- Insufficient ecological management – soils are largely left to natural regeneration and are not being recultivated or rehabilitated.

As a result of these processes, soils in industrial areas often completely lose their ability to store and store carbon, which poses a long-term ecological challenge.

Despite their extremely degraded state, industrial soils have the potential to store carbon with the right environmental and agronomic approaches. The main contributing factors are:

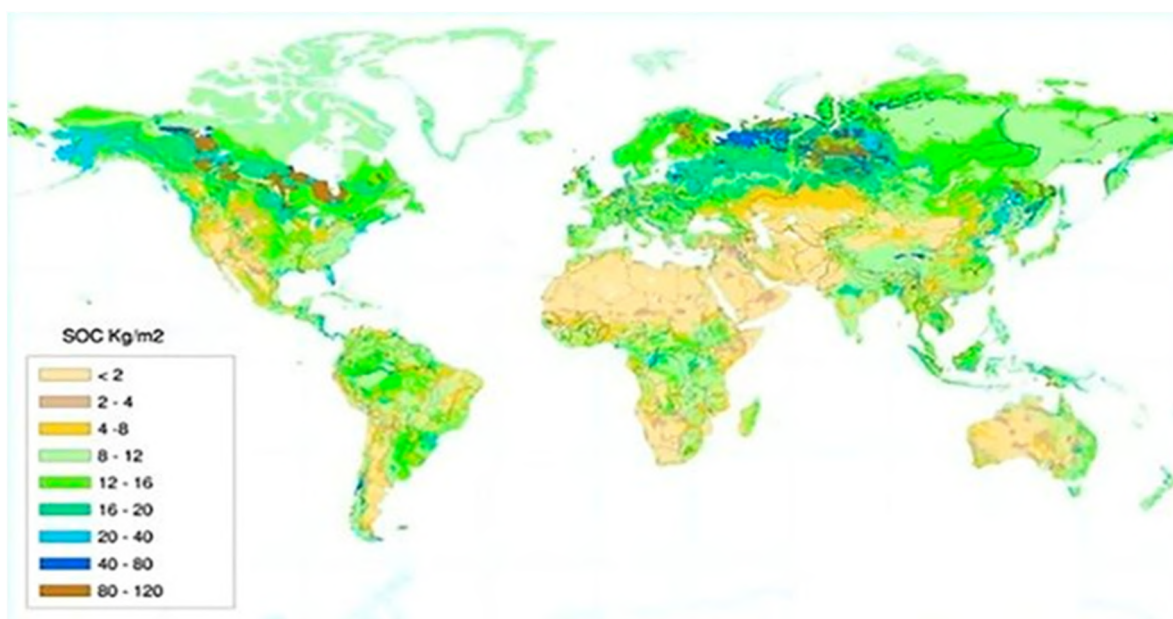


Fig. 1. Soil organic carbon content in kg/m².

Phytoremediation – the integration of plant species that have a high tolerance to heavy metals and pollution and can slowly enrich the soil with organic waste; Phytoremediation of industrial soils is an ecological and innovative process aimed at rehabilitating the soil using the natural abilities of plants. Recognized as a sustainable and environmentally friendly approach, it is attracting significant attention as a promising strategy for reducing the environmental impact of heavy metals and organic compounds. [5,6.]

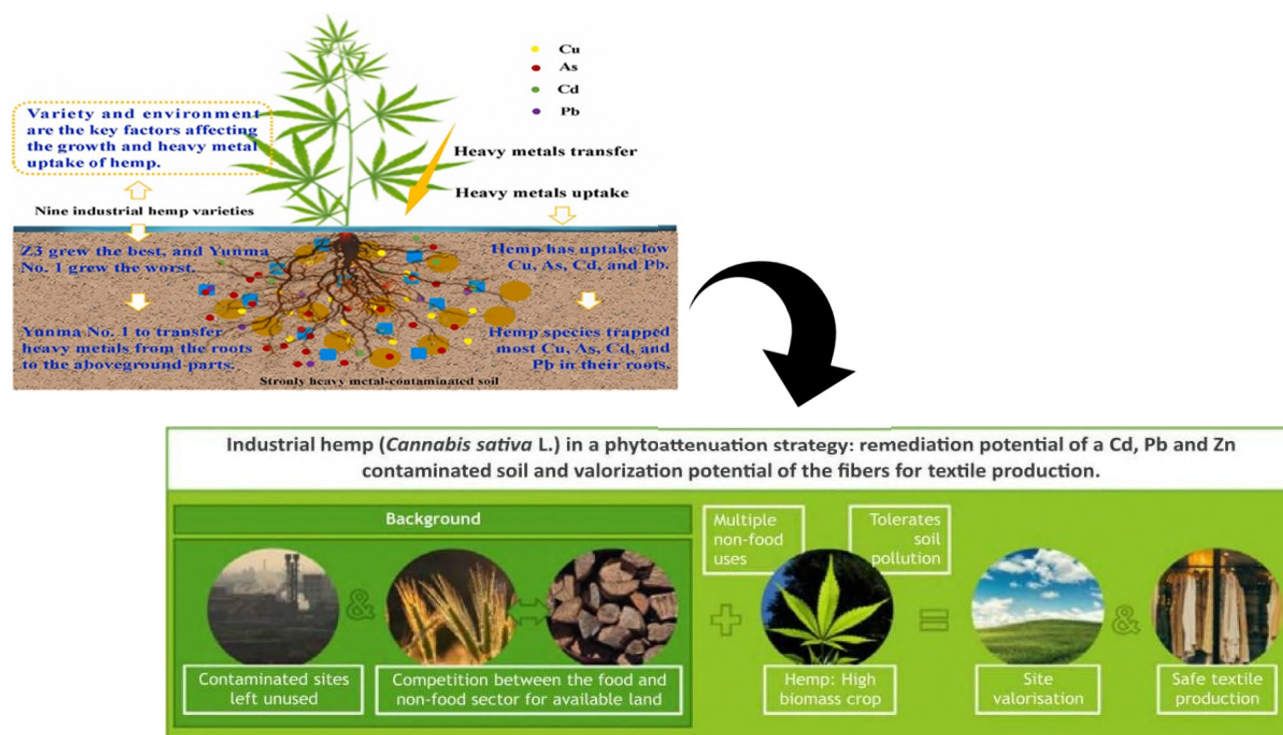


Fig. 2 and Fig. 3. Use of industrial hemp (*Cannabis sativa*) as a phytoremediator.

One interesting example is the use of industrial hemp (*Cannabis sativa*) as a phytoremediator. [Fig.2] Its rapid growth, deep root system, and high biomass production contribute to CO₂ sequestration rates of 8–15 tons per hectare per year – significantly higher than those observed in some forest ecosystems (2–6 tons/ha/year). Industrial hemp has great potential for use in soils contaminated with heavy metals for its safe, non-food uses. We focus on the following cultivar, Wanma. This plant has the ability to accumulate Cu, As, Cd, and Pb in its

roots from contaminated soil and to absorb them from the soil. [7] We will focus on one of the technologies for removing heavy metals – phytoremediation. This is the cheapest and most promising technology.

Georgia has great potential for the introduction of eco-phytoremediation and regeneration, especially in the industrial belt, as industrial areas on the territory of Georgia suffer from soil contamination with radionuclides and heavy metals. Inorganic pollutants such as heavy metals, radionuclides, phosphates, and nitrates are widespread. While some heavy metals are essential for plant growth, excessive levels of lead, cadmium, mercury, and arsenic pose a serious threat to both humans and wildlife. Plants can absorb nonessential inorganic compounds, requiring mechanisms to retain essential nutrients such as Cu, Zn, and Mn, which can be toxic at high concentrations. [8,9.] This method is particularly effective for remediating industrial soils contaminated with heavy metals, petroleum products, or other toxic chemicals.

Fig. 4. Carbon transformation in soil from plant root residues and

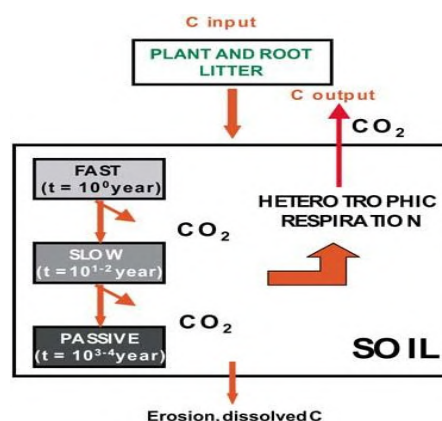
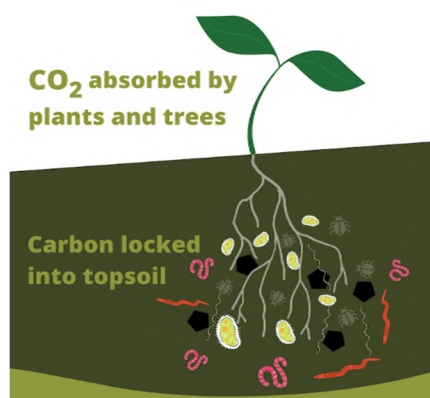


Fig. 5 Carbon uptake, storage, and circulation in the atmosphere

In terms of environmental safety, phytoremediation is less harmful to the environment than chemical and mechanical methods. The technology is more effective in cases of surface contamination. [10]

Results and Discussion

The results showed that industrial hemp biomass absorbs 8–15 tons of CO₂/ha annually, which is higher than the average forest ecosystem (2–6 tons/ha) (Cambridge Institute of Natural Materials, 2022). The use of biochar increases the water retention capacity of the soil and prevents carbon loss through mineralization (Lehmann et al., 2015). An effective phytoremediation model involves treating contaminated soil with a combination of organic amendments, re-vegetation, and continuous monitoring of microbial analysis. Phytoremediation is influenced by environmental factors such as soil type, pH, moisture, and climate. Comprehensive site assessments are essential to identify suitable plants and ensure their sustainability, integrating them into the local ecosystem []. Laboratory and field experiments, along with small-scale pilot studies, are crucial to assess plant tolerance and accumulation capacity, and to validate the feasibility of large-scale projects. To examine the impact of regenerative agriculture on soil carbon sequestration, we searched for studies that measured changes in SOC stock or content or other similar soil carbon parameters (such as total soil carbon or labile carbon). For greenhouse gases, we considered emissions of carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). These three gases are the most common greenhouse gases associated with agricultural land use (USDA, 2022). We selected search terms relevant to regenerative agriculture practices from previous analyses of key regenerative agriculture practices related to climate change mitigation (Bossio et al., 2020, Lal, 2004a, Lal, 2004b, Mikolajczyk, 2021, Smith et al., 2008). These terms were also derived from interviews with farmers in South-east Asia who use sustainable or regenerative soil-based agricultural methods.

Conclusion

The carbon balance of industrial soils can be improved through complex and integrated approaches. Ecophytoremediation strategies, especially the use of industrial hemp and the integration of biochar, repre-

sent a promising path for carbon sequestration. According to current projections, if Georgia activates the implementation of regenerative projects, its carbon levels will be properly controlled, and the country's combined climate goals will be achieved. Important steps are:

- Investing in the development of new technologies and innovations.
- Raising public awareness.
- Supporting the government and international organizations with projects.
- Tightening regulations and supporting environmental activities.

Improving the carbon balance of industrial soils is both an ecological and climate priority. Developing the right management strategies and implementing phytoremediation technologies will allow for the gradual restoration of carbon cycling and the creation of a solid foundation for the regeneration of soil ecosystem services.

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